Relationship between Topographic Variables and Land Cover in the Simen Mountains National Park, a World Heritage Site in Northern Ethiopia

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Abstract- **Altitude, aspect, and slope influence the distribution of land cover types. This paper shows the relationship of land cover distribution with these topographic variables. Geographic information system (GIS) and remote sensing (RS) technologies were used. Information on land cover was obtained by digital classification of a landsat satellite image of 2003. A digital elevation model (DEM) was used to generate elevation, slopes, and aspect information. The land cover map was overlaid with altitude, slope and aspect maps. The result gives quantitative data on the occurrence of the land cover classes of Erica-dominated forest, mixed forest, shrubland, agriculture and grassland as a function of altitude, slope and aspect. Forests were found mainly on north- and northwest-facing slopes of medium and high inclination. Agriculture prevailed at altitudes of 3,000-3,500 m at gentle slopes of different aspects, while grassland dominated at 3,500-4,000 m on gentle, mainly south-facing slopes. Further study is suggested to investigate the significance of these findings for wildlife habitat distribution and, subsequently, for park management.**

Keywords- Altitude; Aspect; DEM; GIS; Land Cover; Slope; Aspect

I. INTRODUCTION

The Simen Mountain National Park (SMNP), which is located in northern Ethiopia, is a spectacular landscape where massive erosion over millions of years has created jagged mountain peaks, deep valleys and sharp precipices dropping some 1,500 m (Fig. 1).

Fig. 1 The spectacular physical features of SMNP (Photo by Demel Teketay)

The park is well known for its outstanding botanical, zoological and agricultural richness owing, primarily, to the geology and climate [1]. SMNP is also of global significance for biodiversity conservation since it is home to globally threatened species, including the endemic iconic Walia ibex, wild mountain goat, Gelada baboon and Ethiopian wolf [1–5]. SMNP forms part of the Afroalpine center of plant diversity and the eastern Afromontane biodiversity hotspot. In recognition of the importance of preserving this unique natural heritage, SMNP was established in 1969 [2, 3], and it was inscribed and listed as a World Heritage Site by UNESCO in 1978 [3].

Simen is a mountainous area where unique botanical and zoological combinations of species have been able to resist human interference because of the extreme topography and altitudinal range of the landscape. Particularly worth of mentioning are the Walia ibex endemic to Simen, the Simen fox (Ethiopian wolf) endemic to Ethiopia, and the vegetation belts typical of Ethiopia, which can be seen in their most extended altitudinal range in succession [4, 6].

For proper management of the park and, in particular, as a basis for decision making in operations with the aim of biodiversity conservation, reliable information on land cover is needed to assess the threats to and the opportunities for the conservation of wildlife habitats.

Land cover denotes the actual distribution of physical and biological features of the land surface. To a large extent, land cover is given by the vegetation cover. In general, reliable land cover data are used for global change studies, including climate change, biodiversity conservation, ecosystem assessment and environmental modelling [7]. Up-to-date information on land cover is crucial for environmental planning and management [8]. Both spatial and temporal information on land cover is required to undertake management interventions and other mitigation measures [9].

There are two major methods for capturing spatially inclusive and comprehensive information on land cover and land cover change: direct field survey and analysis of remotely sensed imagery. A main advantage of field surveys may be seen in the potential of thematically detailed differentiation. The disadvantages include the time and effort required to cover large areas, especially in regions with poor infrastructure and complex terrain such as the SMNP. On the

other hand, remote sensing allows for efficient collection of land cover data over large areas. Remotely sensed imagery (aerial photos and satellite images) from different acquisition dates may be used to study land cover change. The result is obtained by objective and transparent procedures. However, the thematic resolution (potential to differentiate between land cover categories) is limited as compared to field surveys.

Disparate national and regional sources of statistics provide no definite data on land cover status in Ethiopia, especially on forest cover. Furthermore, there is no universally accepted way to measure fragmentation and to assess the complex effects of the landscape pattern on ecosystems. Documentation of spatially referenced data on land cover/use practice is lacking for Ethiopia in general and the SMNP in particular. Consequently, the environmental changes are insufficiently perceived and understood by decision-making bodies and the local users of natural resources in order to initiate further management interventions. Insufficient knowledge and lack of information on environmental change can lead policy makers to poorly justify and undertake unsound environmental decisions, which, in turn, can result in inappropriate and unsustainable natural resources management [10, 11].

Land cover depends on both environmental variables and socioeconomic influences, leading to specific land use. Among the environmental variables, topography is of special importance. Topographic variables comprise altitude, slope and aspect. Data on these variables can be deduced with GIS methods from digital terrain models, which are available from different sources in different quality [12]. The patterns of altitude, slope and aspect bring about the patterns, the heterogeneity and the complexity of climate, soil, vegetation, fauna, land cover and, in connection with socio-economic interactions, land use [13, 14].

Despite various ongoing efforts, gaps still exist in the understanding of the spatial distribution of land cover with respect to the topographic variables: altitude, aspect and slope. This understanding, however, is essential to comprehend the complete system of ecological interactions between environmental variables, socioeconomic factors as well as flora and fauna (Fig. 2). The aim of any environmental management should, therefore, be to control the socio-economic input factors in such a way that the target factors of flora and fauna develop in conformity with biodiversity principles.

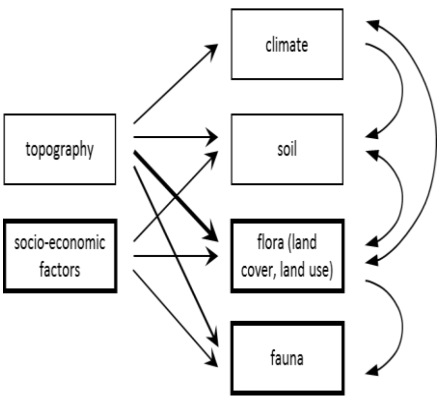

Fig. 2 Ecological interactions relevant in environmental management (Input and output boxes are indicated with thick boundaries. The relationship studied in this work is indicated by the thick arrow)

The specific objective of this study was, thus, to assess the location and extent of each land cover category in relation to topographic variables with the help of GIS. The study is aimed at filling the information gap of land cover distribution across different topographic variables (altitude, aspect and slope).

II. MATERIALS AND METHODS

A. Study Site

The SMNP is situated approximately between 13°09′ and 13°12′ N and 38°00′ and 38°12′ E [14, 15] (Fig. 3).

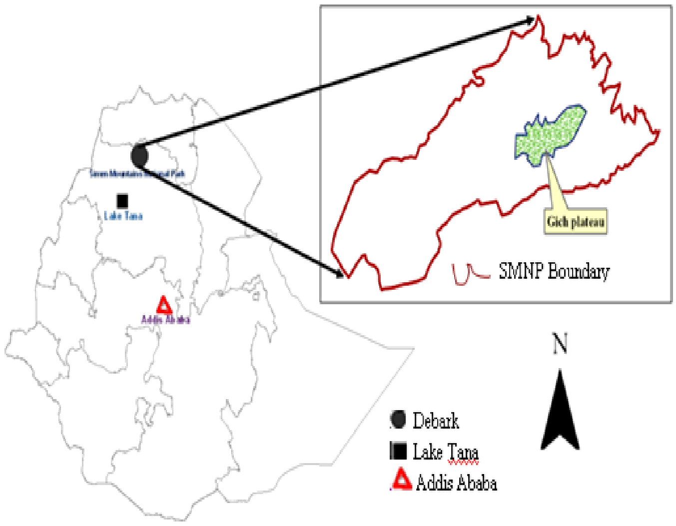

Fig. 3 Location of the study area

The nearest town is Debark in the North Gonder Zone, northwestern Ethiopia. It is about 920 km north of Addis Ababa. The altitude of the study area ranges from 1,900 to 4,430 m. It has an Afro-alpine undulating grassland plateau with steep escarpments lying towards both the north and east direction, giving spectacular views of peaks and canyons of areas found outside the boundary of the park. There are astonishing V- and U-shaped canyons due to geological processes. The rainfall pattern is characterized by a single rainy season, whereby the highest amount of precipitation is between June and September [4]. The average annual rainfall is between 1,350 and 1,550 mm and varies with altitude [3, 4]. Temperature ranges from - 2 to 18 ℃.

Due to differences in land use practice, geological events, topography and climate, different soil types are found in the SMNP. Andosol type of soil is found on uncultivated land above 3,000 m, whereas below 3,000 m and on cultivation land above 3,000 m, the dominant types of soil are Phaeozem, Vertisol, Luvisol, Regosol and Leptosol [4]. The grassland is dominantly covered with Andosol. The very small area with no agricultural potential is attributed to Fluvisol. The park area is made up of thick basalt deposited on Mesozoic sandstone and limestone, Precambrian crystalline basement, and harder rocks on the foot of the escarpment [3].

The main source of income and livelihood strategy of the people around SMNP is agriculture and livestock production [4, 15]. In SMNP, different types of land cover have been identified and categorized by various studies [4, 13, 14]. These are cultivation land, grassland, bushland (shrubland), forest land and escarpment (unusable land).

The socioeconomic background and the natural condition of the area contributed to the existence of these land cover types. Hurni and Ludi [4] indicated different habitats with respect to different land cover types. According to Nievergelt et al. [6], agricultural activities and animal husbandry were the major two activities intensively practiced in the SMNP.

B. Data Collection and Analyses

In the study described here, a Landsat ETM+ data set of 2003 was used as a basis for land cover mapping. The land cover map was produced from this data set by multispectral classification [13].

TABLE Ⅰ LAND COVER CLASSES

Cover Class	Characterization Features
Agricultural/Cultivated Land	Cultivated and fallow land has a characteristic pattern, e.g. sharp edges between fields and dark to grey colour in the Landsat image (4, 3, 2 colour composition), unless the land lies fallow (Hurni and Ludi, 2000; Amsalu *et al.*, 2007).
Grassland/Pasture	Land under permanent pasture and grassland, grassland mixed with giant lobelias (*Lobelia rhynchopetala* Hemsl.), and homogeneous with no pattern compared to agricultural land (Hurni and Ludi, 2000).
Mixed and Matured Natural Forest*	Natural forests and woodland with a composition of different tree species.
Erica-dominated Forest*	One dominating species (*Erica arborea* L. representing more than 95% of the mix).
Shrubland*	Shrubs, bushes and young tree species, bright red on the Landsat image (4, 3, 2 colour composite).

*Based on field data, modification of the classification scheme of Hurni and Ludi [1].

A Digital Elevation Model (DEM) from the Shuttle Radar Topography Mission (SRTM) program [16] with a grid spacing of 90 m was acquired to be used for georeferencing the Landsat image and to derive the topographic variables, namely elevation, aspect and slope.

In the field, the coordinates of ground control points (necessary for geo-referencing) were measured with GPS. Representative reference areas (subdivided into training areas or supervised classification and test areas for accuracy assessment) were selected for every land cover class. The land cover categorization scheme was based on Hurni and Ludi [4] and Amsalu et al. [17] with some modifications (Table Ⅰ). The location of the reference areas was determined by GPS measurements in order to locate them on the geo-referenced image. Also, the different land cover classes were studied in order to understand their features and to support visual delineation of the reference areas in the image [13].

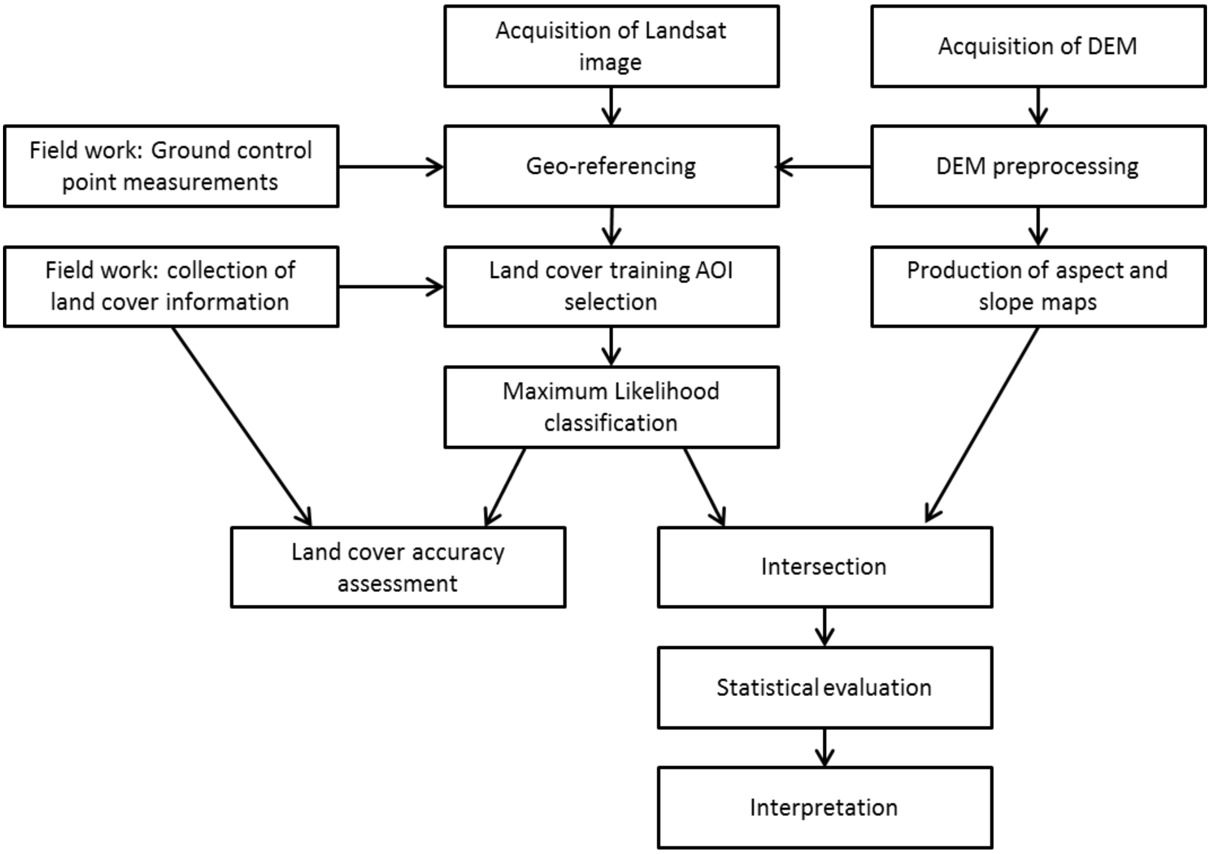

Fig. 4 Work flow for land cover classification

1) Land Cover:

A land cover map was produced from the Landsat ETM+ image (Fig. 4). The work flow is show in the centre part of the diagram. The image was geo-referenced to the UTM projection system WGS-1984-UTM-Zone37N using 69 ground control points and the SRTM digital elevation model. The total Root Mean Square Error was 0.95 pixels (28.5 m). The re-sampling method used was nearest neighbor [13].

The method used to classify the Landsat image with respect to land cover was maximum likelihood supervised classification using ERDAS Imagine 9.1 software [18]. The categories used were those of Table Ⅰ, with an additional shadow category, which also included the unclassified pixels [14]. Areas of Interest (AOIs) were selected as training areas for classification. The training points were well distributed in the area of each land cover type. The numbers of sample AOIs for agriculture, natural mixed forest, pure forest, shrubland, grassland and shadow were 128, 50, 53, 65, 56 and 34, respectively. The accuracy of the resulting land cover map, as determined with independent test AOIs, was characterized by an overall accuracy of 88% and a kappa value of 85% [13].

2) Topographic Variables:

Topographic variables, i.e., altitude, aspect and slope, were deduced from the SRTM digital elevation model. All processing was done with the ERDASTM Imagine modeler [18]. In a preprocessing step (see Fig. 4), obvious errors and holes in the data set were eliminated and filled.

Altitude is one of the variables determining the distribution of land cover classes. The natural distribution of forests is sensitive to altitude due to the physiological requirement of plant species. The altitudinal ranges were categorized into five classes with an interval of 500 m. The topographic variable aspect influences parameters such as exposure to sunlight, drying winds and evapo-transpiration. Hence, aspect has implications to physiological and ecological requirements of the species. In this particular study, an aspect map of the SMNP was produced showing eight aspect categories, namely: north (337.5 – 22.5°), northeast (22.5 – 67.5°), east (67.5 – 112.5°), southeast (112.5 – 157.5°), south (157.5 – 202.5°), southwest (202.5 – 247.5°), west (247.5 – 292.5°) and northwest (292.5 – 337.5°) [13]. The difference in aspect between neighbouring categories was, thus, 45°. Slopes were classified into six categories following the work of Hurni [3].

3) Relationship between Land Cover and Topographic Variables:

The distribution of land cover classes across the topographic variables was determined by thematic overlay. For this purpose, the datasets with the topographic variables were resampled to the pixel size of the land cover map (30 m Landsat pixel size) and overlaid with this.

III. RESULTS AND DISCUSSION

The total size of the different land cover classes ranges between 2,160 (mixed forest) and 3,399 (agricultural land) ha while the unclassified land covered a total of 988 ha across the different altitudinal ranges, aspects and slope ranges (Tables Ⅱ, Ⅲ and Ⅳ). The altitudinal ranges of these land cover classes more or less correspond with the four distinct altitudinal belts of vegetation recognized in SMNP by Hurni [1: 409 in Fig. 4] and their characteristics. These are *Acacia* savanna belt below 2,000 m, montane forest belt between 2,000-3,000 m, subalpine highland belt between 3,000-3,700 m and Afroalpine grassland between 3,700 and 4,400 m.

TABLE Ⅱ EXTENT OF THE ALTITUDINAL RANGES ACROSS THE STUDY AREA AND DISTRIBUTION OF LAND COVER CLASSES WITHIN EACH ALTITUDINAL RANGE

Land Cover Class		**Altitudinal Range (m)**						
		< 2,000	**2,000-2,500**	**2,500-3,000**	**3,000-3,500**	**3,500-4,000**	**4,000-4,500**	**Total**
Mixed Forest	Area (ha)	45.45	697.86	1,000.86	318.69	94.59	0.09	2,160.40
	Proportion (%)	2.10	32.30	46.33	14.75	4.38	0.00	100.00
Erica-fominated Forest	Area (ha)	3.42	109.17	551.88	1,014.12	492.93	1.62	2,173.14
	Proportion (%)	0.16	5.02	25.40	46.67	22.68	0.07	100.00
Shrubland	Area (ha)	69.57	603	772.83	559.8	303.75	1.08	2,310.03
	Proportion (%)	3.01	26.10	33.46	24.23	13.15	0.05	100.00
Grassland	Area (ha)	30.96	190.17	217.17	378.27	2,007.45	52.38	2,876.40
	Proportion (%)	1.08	6.61	7.55	13.15	69.79	1.82	100.00
Agriculture	Area (ha)	71.37	361.89	559.98	1,842.93	561.87	1.08	3,399.12
	Proportion (%)	2.10	10.65	16.47	54.22	16.53	0.03	100.00
Shadow	Area (ha)	4.23	80.91	349.92	423.45	129.51	0.09	988.11
	Proportion (%)	0.43	8.19	35.41	42.85	13.11	0.01	100.00
Total	Area (ha)	225.00	2043.00	3455.64	4537.26	3590.10	56.34	13907.34
	Proportion (%)	01.62	14.69	24.85	32.62	25.81	0.41	100.00

TABLE III SPATIAL DISTRIBUTION OF INDIVIDUAL COVER CATEGORIES ACROSS THE DIFFERENT ASPECTS AT SMNP

Land Cover Class Azimuth (°)	North 337.5 - 22.5	Northeast 22.5 - 67.5	East 67.5 - 112.5	Southeast 112.5 - 157.5	South 157.5 - 202.5	Southwest 202.5 - 247.5	West 247.5 - 292.5	Northwest 292.5 - 337.5	Total
Mixed Forest	621.45	185.04	65.97	42.30	35.91	136.44	307.26	766.17	2,160.54
Erica-Dominated Forest	548.82	160.02	53.64	73.53	127.26	101.70	274.86	833.31	2,173.14
Shrubland	424.44	360.45	311.76	287.73	193.77	165.15	200.70	366.03	2,310.03
Grassland	176.31	128.79	146.88	506.43	723.78	426.69	386.73	380.79	2,876.40
Agriculture	316.35	223.56	317.79	590.04	549.36	401.58	428.67	571.77	3,399.12
Shadow	227.52	25.47	8.46	3.87	3.96	32.49	214.47	471.87	988.11
Total	2,314.89	1,083.33	904.50	1,503.90	1,634.04	1,264.05	1,812.69	3,389.94	13,,907.34
Proportion (%)	16.65	7.79	6.50	10.81	11.75	9.09	13.03	24.38	100.00

TABLE IV SPATIAL DISTRIBUTION OF COVER CATEGORIES ACROSS SLOPES, AND THEIR TOTAL AND PERCENTAGE AREA COVERAGE AT SMNP

Land Cover Class	Slope (°)						
	0-5	6-10	11-20	21-30	31-45	46-87	Total
Mixed Forest	11.25	70.74	454.05	696.42	724.50	203.58	2,160.54
Erica-dominated Forest	8.91	76.41	557.82	525.42	681.12	323.46	2,173.14
Shrubland	25.56	156.60	659.70	644.58	596.97	226.62	2,310.03
Grassland	233.64	1031.04	910.89	254.43	348.66	97.74	2,876.40
Agriculture	155.07	953.19	1224.18	496.53	418.32	151.83	3,399.12
Shadow	1.89	10.98	43.11	90.45	321.03	520.65	988.11
Total	436.32	2,298.96	3,849.75	2,707.83	3,090.60	1,523.88	13,907.34
Proportion (%)	3.14	16.53	27.68	19.47	22.22	10.96	100.00

A. Land Cover Distribution across Altitude

The elevation determines the distribution of vegetation and is a typical characteristic of mountain regions [19]. More than 99% of the study area is in the range of 2,000 - 4,000 m (Table Ⅱ). Only about 1.6 and 0.4 % of the areas are at the altitudinal range of < 2,000 and 4,000-4,500, respectively. The elevation category of 3,000 - 3,500 m is the most dominant (32.67%), followed by the altitudinal ranges of 3,500-4,000 and 2,500-3,000 m. The altitudinal range of 4,000-4,500 m has the lowest cover.

The presence of mixed forest (Fig. 5) and shrubland (Fig. 6) increased with altitude up to the range of 2,500-3,000 m and declined thereafter (Table Ⅱ; Fig. 7), indicating that this altitudinal range supports the optimum distribution of the mixed forest and shrubland. This findings match with the descriptions presented by Hurni [1] on the montane forest belt at SMNP. The areas from 2,500-3,000 have been characterized by evergreen broad-leaved montane woodland (forest) with species of *Sygium, Maesa, Rhus, Myrica, Dombeya* on moist sites and evergreen narrow-leaved montane woodland with species of *Olea, Nuxia, Juniperus, Maytenus* and *Acacia* on dry sites. The wild animals reported from the areas include Crested porcupine, Spotted hyena, Serval cat, Leopard, Walia ibex, Hamadryas and Anubis baboons and Grivet monkey. Wheat, barley and pulses are cultivated, and the areas are annually grazed.

Fig. 5 Mixed forest land cover (Photo by Menale Wondie)

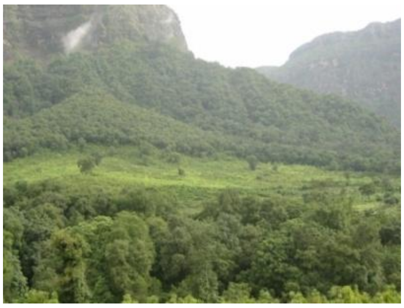

Fig. 6 Shrubland land cover (Photo by Menale Wondie)

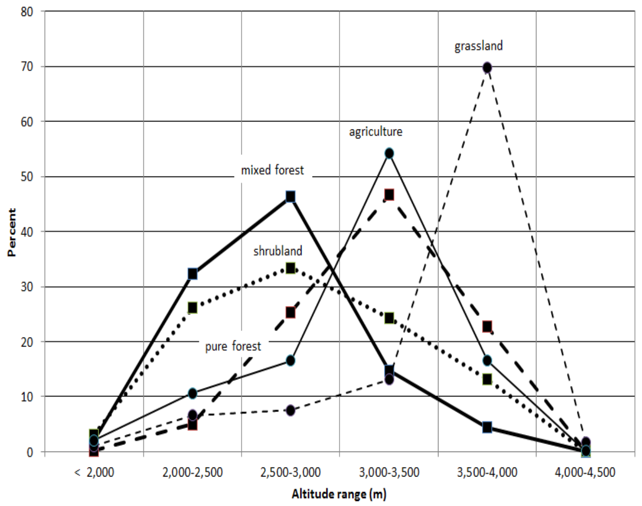

Fig. 7 Distribution of land covers across ranges of altitude

The areas covered by the Erica-dominated forest (about 47%) (Fig. 8) and agricultural land (about 54%) (Fig. 9) peak at 3,000-3,500 m altitudinal range and decline sharply thereafter (Fig. 7). Concurrent to this finding, this altitudinal range has been shown to represent areas with evergreen ericaceous woodland with species of *Erica*, *Olea*, *Nuxia*, *Maytenus*, *Hagenia* and *Hypericum* on moist, and *Acacia* on drier sites, moist grassland on natural terraces, barley, wheat

and pulses cultivation as well as grazing on fallow land and wetlands [1, 20]. The wild animals inhabiting this range include Walia Ibex, Gelada baboons, Golden jackal, Simen fox, spotted hyena, Serval cat, Caracal, Grims duiker and klipspringer [1].

Fig. 8 *Erica*-dominated land cover (Photo by Menale Wondie)

Fig. 9 Agricultural land cover (Photo by Menale Wondie)

Friis et al. [20] also reported that around 3,000 m, large, tree-like individuals of *E. arborea* were commonly observed and dominated grooves of tall shrubs or small trees with *Hypericum revolutum* and *Rosa abyssinica*, and this vegetation continued, mostly, up to 3,200 m. A mixture of *Lobelia rhynchopetalum* and *E. arborea* occurred at 3,650 m. *Erica arborea* L. occurred up to nearly 3,800 m in places with mist and abundant oreographic rain. In slightly drier parts of the Simen Mountain, 3,600 m seemed to be the upper most limit of ericaceous bushland. In some areas, the terrain intensively cultivated reaches just above 3,000 m. *Erica arborea* and *Kniphofia foliosa* occur in a few uncultivated places in these areas, where the potential vegetation would be ericaceous bushland.

The areas covered by grassland (Fig. 10) peaked at the 3,500-4,000 m (about 70%) altitudinal range (Fig. 7). This peak is within the Afroalpine belt, which is characterised by the distinctive life forms of giant rosette plants, tussock grasses (and sedges), acaulescent rosette plants, cushion plants and sclerophyllous shrubs (and dwarf-shrub) [20]. The lower zones of this belt are characterized by small trees, shrubs and shrubby herbs while the upper zones are characterized by giant herbs, small herbs and grasses. The wild animals inhabiting these areas include rodents, Simen Fox, Gelada baboon, Klipspringer, rarely Walia ibex, Golden jackal, Spotted hyena, Serval cat, African wildcat and Rock hyrax [1]. These are areas used for grazing and as sources of grass for roof thatching. They are little transformed by people, except on overgrazing areas in the vicinity of villages.

Below 2,000 m, the areas support, mainly, *Acacia* woodland, Spotted hyena and Leopard. People cultivate sorghum, maize, tef and graze their livestock. These areas were subjected to excessive transformation due to annual burning of scrubs and grasses by the local people [1]. The areas from 2,000-2,400 m have been characterized by semi-deciduous montane woodland with species of *Cordia*, *Ficus*, *Stereospermum*, *Croton* and *Pterolobum* as well as *Acacia* woodland on drier sites. Bushpig and Buskbuck are common.

A

B

Fig. 10 Grassland areas being grazed with Walia ibex (A) and domestic animals (B) (Photo by Menale Wondie)

The upper altitudes of SMNP (3,200-4,500 m) are characterized by northerly winds all year round, an increase in cloudiness with altitude, annual rainfall maximum at about 3,500 m, frequent hailstorms, which are highly erosive, occasional snow at higher elevations and frequent frost. The climate is unfavourable for most grains and pulses except barley, potatoes and some vegetables [1]. The lower parts (1,500-3,200 m) are characterized by the (upwardly increasing) influence of the southwest monsoon, convective rain, trade winds only in dry seasons, less frequent hailstorms, no snow, and rare frosts. This altitudinal belt is favourable for most Ethiopian crops and pulses.

B. Land Cover Distribution across Aspect

The areas covered by mixed forest, *Erica*-dominated forest and shrubland peak in both the Northwest and North aspects. The agricultural land cover class peaks in the Northwest and Southeast/South aspects while the highest occurrence of grassland is recorded in the South aspect (Figs. 11 and 12; Table III).

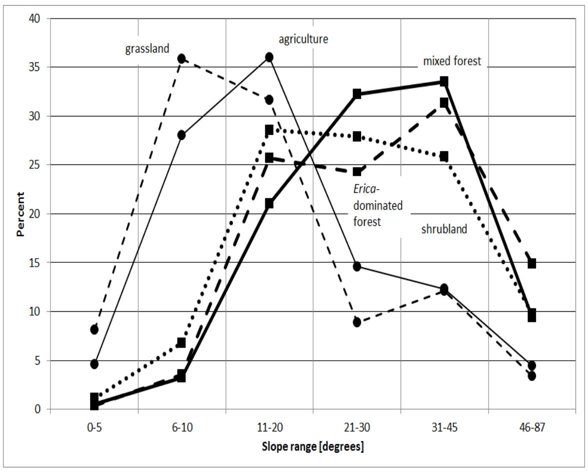

Fig. 11 Distribution of land covers across ranges of aspect

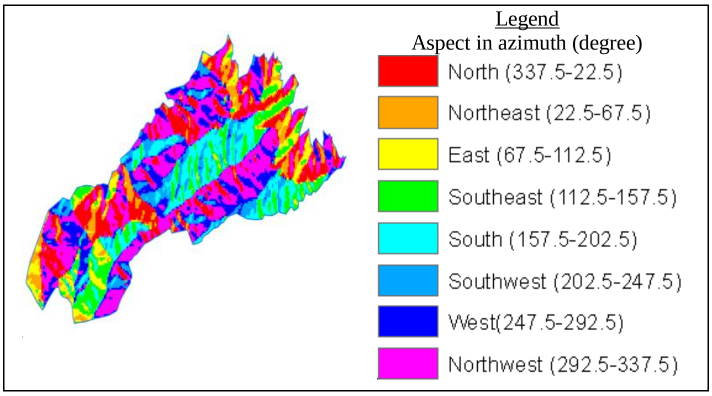

Fig. 12 Spatial distribution of aspects in SMNP

North facing slopes have little sunlight and tend to be cooler than the south, where sun is predominantly shining. Species on the southern slopes are relatively more adapted to evaporation, hot and dry conditions, while species on the north and northwest facing slopes need more water and cooler conditions. This knowledge could be instrumental in future efforts of species selection for plantation development in the study area.

C. *Land Cover Distribution Across Slope*

All land cover categories exhibited more or less bell-shaped distributions along the slope categories (Figs. 13 and 14; Table Ⅳ). Two groups of land cover classes, namely agriculture and grassland, were mainly found at gentle slopes between 6 and 20 degrees, while shrubland and forests (both *Erica*-dominated and mixed forests) had their dominant occurrence at steeper slopes between 21 and 45 degrees.

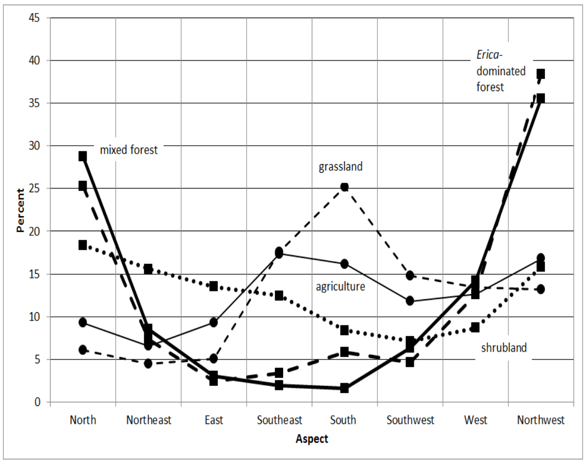

Fig. 13 Distribution of land covers across ranges of slope

The high proportion of crop cultivation (agriculture) and grassland and the low forest cover on gentle slopes are obviously the results of anthropogenic activities. Human settlement is commonly practiced in areas with gentle slopes in the park. This situation induced both crop cultivation and clearance of mixed forest, shrubland and pure forest for household consumption.

Steeper topographic features are not suitable for crop production and grazing due to inaccessibility and fragility of the land. But in the SMNP, as it is also revealed by the results shown in Table Ⅳ, there are steep slopes, which are used for cultivation of crops and animal grazing owing to scarcity of land. In any case, steeper slopes favor the survival of forests (Table Ⅳ).

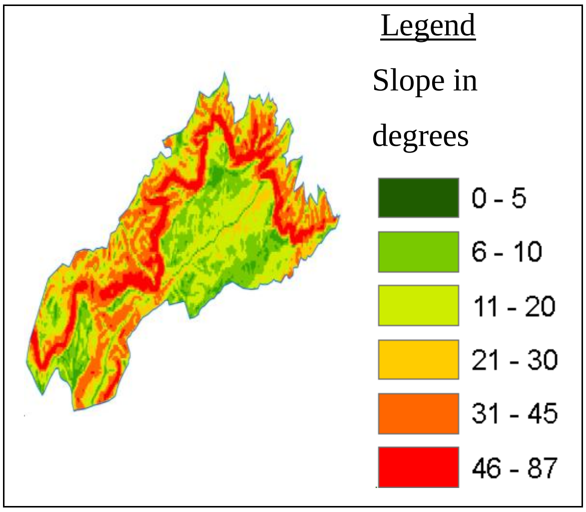

Fig. 14 Spatial distribution of slope SMNP

IV. CONCLUSIONS

This study highlights the relationship between the environmental variables (topography), the management practices carried out in the area (proximity to settlement) and the spatial distribution of different land cover types. The results also showed that integration of GIS and remote sensing is effective in monitoring the overall status and analyzing land cover patterns as a function of environmental parameters such as altitude, slope and aspect. It was possible to detect and categorize six different land cover classes by using Landsat ETM+ 2003 datasets.

Major anthropogenic activities (crop cultivation and livestock grazing) are dominantly undertaken on the gentle slopes. According to Nievergelt et al. [6], major ecosystem changes due to human activities are crop cultivation and animal husbandry.

The ecograms of the species can be developed by analyzing the altitude, aspect, slope and other environmental variables and ecological management intervention can, thus, be facilitated. Wildlife habitat management and planning can be carried out in relation to environmental variables and depending on the resource (land cover type) that exists in the area. Assessment and adjustment of park management practices requires monitoring the environmental conditions. Therefore, different management activities of the major wildlife habitat conservation sites can be designed using the information of altitude, aspect and slope in the SMNP. For instance, Hurni and Ludi [4] indicated different habitats in relation to land cover types on a study area of around 47,069 ha of land inside the park and its buffer zones.

Forests develop preferentially on high and steep terrain, while agriculture is scarce on steep terrain. Detection of different environmental parameters might also help to know, plan and create a diversity of habitats available to plant and animal species, and contribute to overall increase of the species diversity. Therefore, wildlife habitats, conservation sites and management units can be identified and mapped with the help of GIS and RS to set up development and management strategies in relation to environmental parameters preferred by the respective wildlife.

The spatial analyses of land cover in relation to environmental variables indicated the overall situation of the park. It can, thus, be used as a planning tool to optimize

protection of the target species and indicator of the overall environmental quality. Hence, management activities can be designed using the information of the location of altitude, aspect and slope in the SMNP.

This study can be used as a basis of information for further identification of different wildlife habitats, ecological conditions and future studies on biodiversity conservation and management. The land cover information existing in the park helps to develop the carrying capacity of the important species. It is also useful as a reference in the analysis of the ecological trends on a time-series basis and can be used for planning measures for restoration of the ecosystem.

Further study is suggested on the relationship of environmental variables, land cover, and wildlife distribution. This will help to understand the ecological processes and environmental conditions for the conservation of endemic and threatened species. The Afroalpine zone at the higher elevations dominated by grassland is used for endemic mammals as a feeding, sheltering and grooming site [4, 6]. This study also indicated that forests and grassland ecosystem are found in the high altitude and steep areas of the park. Hence, these ecosystems have to be maintained and managed to protect wild animals being threatened or endangered. Alternative options for livelihood strategy have to be designed to minimize the disturbance from the human settlement in these fragile environments.

Resource managers and policy decision makers can use this result for wildlife management and conservation in relation to the environmental status of the park. Status of natural resources with respect to different environmental variables needs to be investigated to protect the most fragile ecosystem in the verge of vanishing. We suggest that acquiring better spatial resolution of land cover data would add to the refinement of ecological pattern analyses in the park and, therefore, the assessment of resources on a time series.

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